

## **Sound-Speed Fluctuations in the Philippine Sea**

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Award Number: N00014-07-1-0270  
<http://npal.ucsd.edu>

### **LONG-TERM GOALS**

As part of the North Pacific Acoustic Laboratory (NPAL) program, the long-term goals of this project are to understand the physics of long-range, broadband propagation in deep water and the effect of oceanic variability on acoustic propagation.

### **OBJECTIVES**

Long-range acoustic propagation in the ocean is ultimately limited by scattering due to oceanic variability. The objective of this effort is to better understand the time-space scales of ocean variability in the Philippine Sea and the effect of this variability on acoustic propagation.

Temperature fluctuation statistics from Seabird MicroCAT (Conductivity and Temperature) sensors mounted on the vertical line array in 2004-2005 during SPICEX in the North Pacific indicate that variability associated with internal-wave activity is accurately described by the Garrett-Munk (GM) internal wave energy spectrum (Van Uffelen et al., 2010). Acoustic propagation simulations incorporating stochastic sound-speed perturbations consistent with the GM spectrum also showed good agreement with received vertical line array acoustic data. This agreement was consistent both for deterministic arrivals as well as extensions of the acoustic timefront into geometric shadow-zones. The extent and intensity of these extensions were shown to be consistent with scattering caused by internal-wave sound speed perturbations at a level of 1 GM (Van Uffelen, 2009).

The Philippine Sea is a very different and much more dynamic environment with anticipated high levels of internal wave activity. One objective of the year-long NPAL Philippine Sea Experiment (PhilSea10) and the month-long pilot study conducted in April 2009 (PhilSea09) is to determine the internal-wave environment in the Philippine Sea. Sound-speed fluctuation measurements and acoustic data will be analyzed to determine whether the internal wave structure can be described using the GM spectrum, as it was in the North Pacific, and what effect the variability has on long-range acoustic propagation.

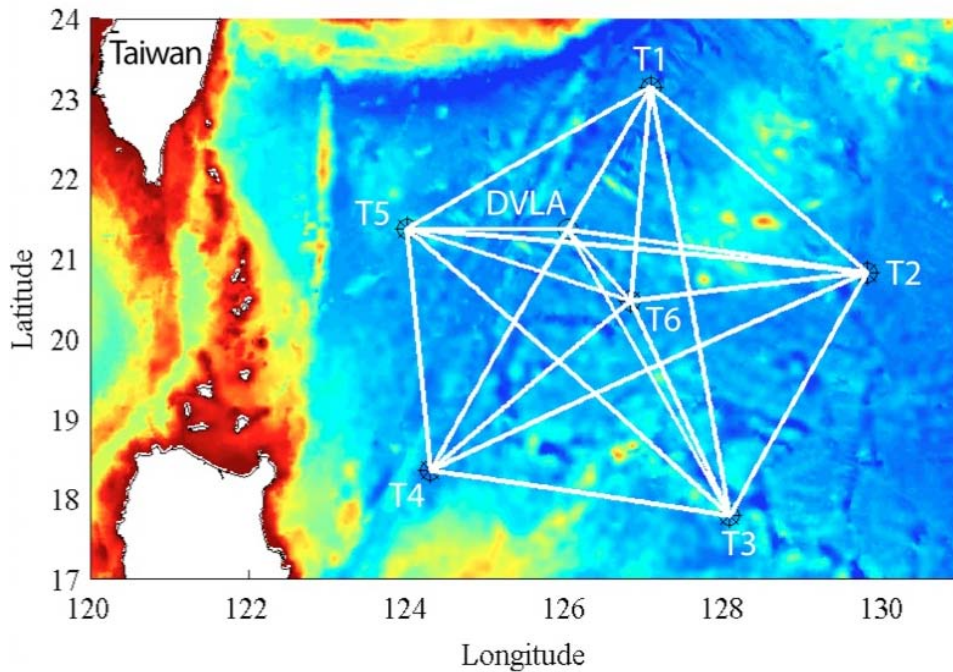
The full tomography array deployed in PhilSea10, consisting of six transceivers and a vertical receiving array, will be recovered in spring 2011. An understanding of the fluctuations due to internal

Report Documentation Page				Form Approved OMB No. 0704-0188	
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1. REPORT DATE <b>2010</b>		2. REPORT TYPE		3. DATES COVERED <b>00-00-2010 to 00-00-2010</b>	
4. TITLE AND SUBTITLE <b>Sound-Speed Fluctuations in the Philippine Sea</b>				5a. CONTRACT NUMBER	
				5b. GRANT NUMBER	
				5c. PROGRAM ELEMENT NUMBER	
6. AUTHOR(S)				5d. PROJECT NUMBER	
				5e. TASK NUMBER	
				5f. WORK UNIT NUMBER	
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) <b>University of California, San Diego, Scripps Institution of Oceanography, 9500 Gilman Drive, Mail Code 0225, La Jolla, CA, 92093-0225</b>				8. PERFORMING ORGANIZATION REPORT NUMBER	
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)				10. SPONSOR/MONITOR'S ACRONYM(S)	
				11. SPONSOR/MONITOR'S REPORT NUMBER(S)	
12. DISTRIBUTION/AVAILABILITY STATEMENT <b>Approved for public release; distribution unlimited</b>					
13. SUPPLEMENTARY NOTES					
14. ABSTRACT					
15. SUBJECT TERMS					
16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT <b>Same as Report (SAR)</b>	18. NUMBER OF PAGES <b>6</b>	19a. NAME OF RESPONSIBLE PERSON
a. REPORT <b>unclassified</b>	b. ABSTRACT <b>unclassified</b>	c. THIS PAGE <b>unclassified</b>			

waves from the PhilSea09 pilot study will help determine whether the full tomography experiment could be a candidate experiment for internal wave tomography.

## APPROACH

In April/May 2010, six transceiver moorings (T1-T6) and an extensive vertical receiving array (DVLA) were deployed southeast of Taiwan as part of the PhilSea10 experiment and will remain in place for one year (Figure 1).



***Figure 1: Locations of acoustic source moorings (T1-T6) and receiving array (DVLA) currently deployed as part of the NPAL PhilSea10 Experiment.***

The six transceiver moorings each support Webb Research Corporation (WRC) swept frequency sources with center frequencies of approximately 250 Hz, located at approximately the sound channel axis as well as 4-element receiving arrays located immediately above the sources.

The Distributed Vertical Line Array (DVLA) is comprised of 150 individual hydrophone module receivers, which communicate inductively over the mooring wire with a DVLA Simple Tomographic Acoustic Receiver (D-STAR), which performs precision timekeeping and signals the hydrophone modules to receive [3]. Each hydrophone module receives navigation data from a net of acoustic transponders in addition to tomography transmissions from each of the 6 moored sources.

Multiple types of environmental measurements are being collected to characterize the variability of the ocean environment. Integrated in each hydrophone module is a YSI 46016 precision thermistor to measure temperature along the array. Seabird Temperature Recorders (SBE39) and MicroCAT (Conductivity And Temperature)(SBE 37-SM/SMP) sensors are mounted on the DVLA cable. The T1-T5 source moorings are also populated with MicroCATs and Temperature Recorders. From November 2010 until April 2011, acoustic SeaGliders will also be flying in the upper 1000m of the

ocean in the region of the moorings to collect temperature and salinity data as well as to receive the tomography transmissions from T1-T6.

The PhilSea09 pilot study, consisting of a single source and receiver path (T1 to DVLA) with a range of approximately 185 km, was performed in April 2009 to test the new DVLA technology and to get initial measurements of the ocean environment in the Philippine Sea study area. This initial DVLA deployment consisted of two sub-arrays, one spanning the sound-channel axis (30 hydrophone modules) and the other spanning the surface conjugate depth (30 hydrophone modules).

The estimation of sound-speed fluctuations in the Philippine Sea, from which the strength of the internal wave field can be inferred, requires extensive, precise measurements of temperature and salinity. In addition to the thermistor measurements recorded on the 60 hydrophone modules, the DVLA mooring supported 22 MicroCATs and 8 Temperature Recorders. The T1 mooring, positioned in approximately the same location as in PhilSea10, supported 11 MicroCATs and 19 Temperature Recorders.

## **WORK COMPLETED**

Initial analysis of environmental data was performed for data collected during the PhilSea09 deployment. Temperature fluctuation data from Seabird MicroCAT sensors affixed to the DVLA mooring were compared with the empirical Garrett-Munk internal-wave energy spectrum [4] to determine which energy level (if any) appropriately describes the data.

One hundred hydrophone modules were assembled and tested. The grand total of 168 hydrophones were fully tested and the thermistors were calibrated using the calibration tank operated by the Shipboard Technical Support (STS) group at Scripps Institution of Oceanography (Figure 2) prior to deployment in PhilSea10.



***Figure 2: Four Hydrophone Modules demonstrating calibration configuration in STS calibration tank at Scripps Institution of Oceanography.***

The behavior of the thermistor resistors can be described by the Steinhart-Hart equation:

$$\frac{1}{T} = A + B \ln(R) + C(\ln(R))^3.$$

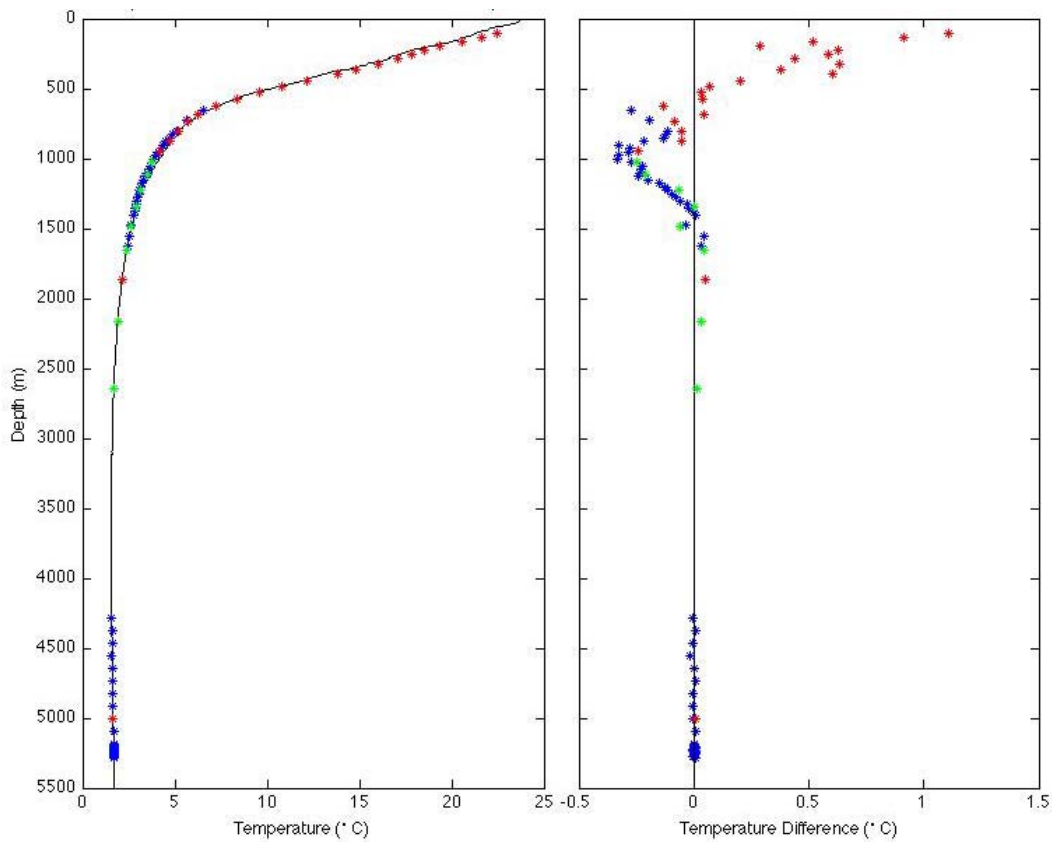
Thermistor coefficients A, B, and C were calculated for each thermistor separately. Thermistors will be re-calibrated upon recovery in April 2011.

The PhilSea10 tomography array, consisting of six acoustic source moorings and a DVLA mooring with 150 hydrophone modules, was successfully deployed, along with associated transponder networks, in April 2010.

## **RESULTS**

Preliminary fluctuation calculations from Seabird MicroCAT sensors indicate that GM internal-wave energy in the upper ocean is significantly higher than what was observed in the North Pacific during SPICEX 2004-2005. In SPICEX, 1GM was a good estimate with regards to the sound-speed fluctuations observed on the MicroCAT sensors. Parabolic equation simulations incorporating sound-speed fluctuations consistent with an internal wave energy level of 1 GM also agreed with scattering of acoustic arrivals observed on hydrophone receivers at ranges of 500 and 1000-km.

The background temperature and sound-speed profiles in the Philippine Sea are well defined by a variety of environmental measurements obtained during PhilSea09 such as CTDs, thermistors incorporated in hydrophone modules on the DVLA, and SeaBird MicroCATs and temperature recorders (Figure 3). Temperatures shown in Figure 3 are an average of all measurements made on yearday 96, the day that the CTD cast was performed on the PhilSea09 deployment cruise.



**Figure 3: Temperature profile at the DVLA from CTD (black), HM thermistors (blue), MicroCATs (red) and Temperature Recorders (green) on yearday 96 (left), and difference from the CTD temperature (right).**

Temperature measurements were collected throughout the duration of the mooring deployment on the hydrophone module thermistors and SeaBird instruments. The hydrophone module thermistors were calibrated after the recovery of the PhilSea09 moorings, prior to deployment for PhilSea10. After calibration, the mean rms difference between the hydrophone module and CTD temperatures for the 20 modules below 5100 m, where temperature should be more or less constant, is  $.0044^{\circ}\text{C}$ , giving an indication of the precision of the thermistors.

## IMPACT/APPLICATIONS

This research has the potential to affect the design of deep-water acoustic systems, whether for sonar, acoustic communications, acoustic navigation, or acoustic remote sensing of the ocean interior.

## RELATED PROJECTS

This project is very closely associated with the project “North Pacific Acoustic Laboratory: Deep Water Acoustic Propagation in the Philippine Sea,” with Peter Worcester as principal investigator and Bruce Cornuelle, Matthew Dzieciuch and Walter Munk as co-investigators. A large number of investigators and their students are also currently involved in ONR-supported research related to the

NPAL project. The Principal Investigators include R. Andrew (APL-UW), A. Baggeroer (MIT), M. Brown (UMiami), T. Chandrayadula (NPS), J. Colosi (NPS), B. Dushaw (APL-UW), G. D'Spain (SIO), K. Heaney (OASIS), F. Henyey (APL-UW), B. Howe (Univ. Hawaii), J. Mercer (APL-UW), V. Ostachev (NOAA/ETL), B. Powell (Univ. Hawaii), I. Rypina (WHOI), R. Stephen (WHOI), I. Udovydchenkov (WHOI), A. Voronovich (NOAA/ETL), and K. Wage (George Mason Univ.).

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## PUBLICATIONS

Van Uffelen, Lora J., Worcester, Peter, F., Dzieciuch, Matthew A., Rudnick, Daniel L., and Colosi, John A. "Effects of upper ocean sound-speed structure on deep acoustic shadow-zone arrivals at 500- and 1000 -km range," J. Acoust. Soc. Am. **127**, 2169-2181. [published, refereed]

## HONORS/AWARDS/PRIZES

Lora Van Uffelen was awarded a student paper award in Acoustical Oceanography for her talk, "Characterization of deep acoustic shadow-zone arrivals" (J. Acoust. Soc. Am., **126**, 2159) presented at the October 2009 meeting of the Acoustical Society of America in San Antonio, TX.